

VISIT...

LANZAROTE
Caliente.COM

29

Wiring and Grounding for Power Quality

29.1	Definitions and Standards	29-1
	The National Electric Code • From the <i>IEEE Dictionary—</i> <i>Std. 100</i> • Green Book (IEEE Std. 142) Definitions • NEC Definitions	
29.2	Reasons for Grounding.....	29-3
	Personal Safety • Protective Device Operation • Noise Control	
29.3	Typical Wiring and Grounding Problems.....	29-5
	Insulated Grounds • Ground Loops • Missing Safety Ground • Multiple Neutral to Ground Bonds • Additional Ground Rods • Insufficient Neutral Conductor • Summary	
29.4	Case Study.....	29-12
	Case Study—Flickering Lights	

Christopher J. Melhorn
EPRI

Perhaps one of the most common problems related to power quality is wiring and grounding. It has been reported that approximately 70 to 80% of all power quality related problems can be attributed to faulty connections and/or wiring. This chapter describes wiring and grounding issues as they relate to power quality. It is not intended to replace or supersede the National Electric Code (NEC) or any local codes concerning grounding.

29.1 Definitions and Standards

Defining grounding terminology is outside the scope of this chapter. There are several publications on the topic of grounding that define grounding terminology in various levels of detail. The reader is referred to these publications for the definitions of grounding terminology.

The following is a list of standards and recommended practice pertaining to wiring and grounding issues. See the section on References for complete information.

National Electric Code Handbook, 1996 edition.

IEEE Std. 1100–1999. *IEEE Recommended Practice for Powering and Grounding Electronic Equipment*.

IEEE Std. 142–1991. *IEEE Recommended Practice for Grounding Industrial and Commercial Power Systems*.

FIPS-94 Publication

Electrical Power Systems Quality

29.1.1 The National Electric Code

NFPAs *National Electrical Code Handbook* pulls together all the extra facts, figures, and explanations readers need to interpret the 1999 NEC. It includes the entire text of the Code, plus expert commentary, real-world examples, diagrams, and illustrations that clarify requirements. Code text appears in blue

type and commentary stands out in black. It also includes a user-friendly index that references article numbers to be consistent with the Code.

Several definitions of grounding terms pertinent to discussions in this article have been included for reader convenience. The following definitions were taken from various publications as cited.

29.1.2 From the *IEEE Dictionary—Std. 100*

Grounding: A conducting connection, whether intentional or accidental, by which an electric circuit or equipment is connected to the earth, or to some conducting body of relatively large extent that serves in place of the earth. It is used for establishing and maintaining the potential of the earth (or of the conducting body) or approximately that potential, on conductors connected to it; and for conducting ground current to and from the earth (or the conducting body).

29.1.3 Green Book (IEEE Std. 142) Definitions

Ungrounded System: A system, circuit, or apparatus without an intentional connection to ground, except through potential indicating or measuring devices or other very high impedance devices.

Grounded System: A system of conductors in which at least one conductor or point (usually the middle wire or neutral point of transformer or generator windings) is intentionally grounded, either solidly or through an impedance.

29.1.4 NEC Definitions

Refer to Fig. 29.1.

Bonding Jumper, Main: The connector between the grounded circuit conductor (neutral) and the equipment-grounding conductor at the service entrance.

Conduit/Enclosure Bond: (bonding definition) The permanent joining of metallic parts to form an electrically conductive path which will assure electrical continuity and the capacity to conduct safely any current likely to be imposed.

Grounded: Connected to earth or to some conducting body that serves in place of the earth.

Grounded Conductor: A system or circuit conductor that is intentionally grounded (the grounded conductor is normally referred to as the neutral conductor).

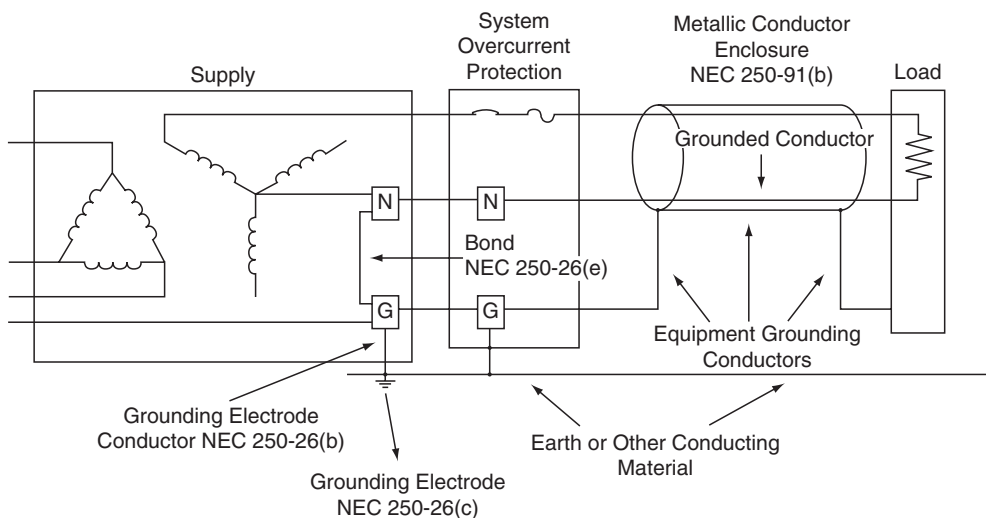


FIGURE 29.1 Terminology used in NEC definitions.

Grounding Conductor: A conductor used to connect equipment or the grounded circuit of a wiring system to a grounding electrode or electrodes.

Grounding Conductor, Equipment: The conductor used to connect the noncurrent-carrying metal parts of equipment, raceways, and other enclosures to the system grounded conductor and/or the grounding electrode conductor at the service equipment or at the source of a separately derived system.

Grounding Electrode Conductor: The conductor used to connect the grounding electrode to the equipment-grounding conductor and/or to the grounded conductor of the circuit at the service equipment or at the source of a separately derived system.

Grounding Electrode: The grounding electrode shall be as near as practicable to and preferably in the same area as the grounding conductor connection to the system. The grounding electrode shall be: (1) the nearest available effectively grounded structural metal member of the structure; or (2) the nearest available effectively grounded metal water pipe; or (3) other electrodes (Section 250-81 & 250-83) where electrodes specified in (1) and (2) are not available.

Grounding Electrode System: Defined in NEC Section 250-81 as including: (a) metal underground water pipe; (b) metal frame of the building; (c) concrete-encased electrode; and (d) ground ring. When these elements are available, they are required to be bonded together to form the grounding electrode system. Where a metal underground water pipe is the only grounding electrode available, it must be supplemented by one of the grounding electrodes specified in Section 250-81 or 250-83.

Separately Derived Systems: A premises wiring system whose power is derived from generator, transformer, or converter windings and has no direct electrical connection, including a solidly connected grounded circuit conductor, to supply conductors originating in another system.

29.2 Reasons for Grounding

There are three basic reasons for grounding a power system: personal safety, protective device operation, and noise control. All three of these reasons will be addressed.

29.2.1 Personal Safety

The most important reason for grounding a device on a power system is personal safety. The safety ground, as it is sometimes called, is provided to reduce or eliminate the chance of a high touch potential if a fault occurs in a piece of electrical equipment. Touch potential is defined as the voltage potential between any two conducting materials that can be touched simultaneously by an individual or animal.

Figure 29.2 illustrates a dangerous touch potential situation. The “hot” conductor in the piece of equipment has come in contact with the case of the equipment. Under normal conditions, with the safety ground intact, the protective device would operate when this condition occurred. However, in Fig. 29.2, the safety ground is missing. This allows the case of the equipment to float above ground since the case of the equipment is not grounded through its base. In other words, the voltage potential between the equipment case and ground is the same as the voltage potential between the hot leg and ground. If the operator would come in contact with the case and ground (the floor), serious injury could result.

In recent years, manufacturers of handheld equipment, drills, saws, hair dryers, etc. have developed double insulated equipment. This equipment generally does not have a safety ground. However, there is never any conducting material for the operator to contact and therefore there is no touch potential hazard. If the equipment becomes faulted, the case or housing of the equipment is not energized.

29.2.2 Protective Device Operation

As mentioned in the previous section, there must be a path for fault current to return to the source if protective devices are to operate during fault conditions. The National Electric Code (NEC) requires that an effective grounding path must be mechanically and electrically continuous (NEC 250-51), have

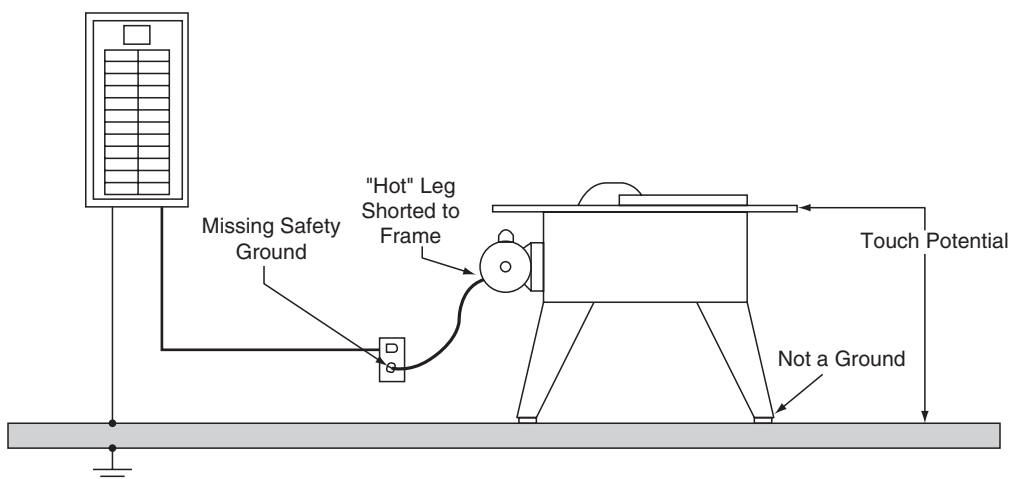


FIGURE 29.2 Illustration of a dangerous touch potential situation.

the capacity to carry any fault currents imposed on it without damage (NEC 250–75). The NEC also states that the ground path must have sufficiently low impedance to limit the voltage and facilitate protective device operation. Finally, the earth cannot serve as the equipment-grounding path (NEC-250–91(c)).

The formula to determine the maximum circuit impedance for the grounding path is:

$$\text{Ground Path Impedance} = \frac{\text{Maximum Voltage to Ground}}{\text{Overcurrent Protection Rating} \times 5}$$

Table 29.1 gives examples of maximum ground path circuit impedances required for proper protective device operation.

29.2.3 Noise Control

Noise control is the third main reason for grounding. Noise is defined as unwanted voltages and currents on a grounding system. This includes signals from all sources whether it is radiated or conducted. As stated, the primary reason for grounding is safety and is regulated by the NEC and local codes. Any changes to the grounding system to improve performance or eliminate noise control must be in addition to the minimum NEC requirements.

When potential differences occur between different grounding systems, insulation can be stressed and circulating currents can be created in low voltage cables (e.g., communications cables). In today's electrical environment, buildings that are separated by large physical distances are typically tied together via a communication circuit. An example of this would be a college campus that may cover several

TABLE 29.1 Example Ground Impedance Values

Protective Device Rating	Voltage to Ground 120 Volts	Voltage to Ground 277 Volts
20 Amps	1.20 Ω	2.77 Ω
40 Amps	0.60 Ω	1.39 Ω
50 Amps	0.48 Ω	1.11 Ω
60 Amps	0.40 Ω	0.92 Ω
100 Amps	0.24 Ω	0.55 Ω

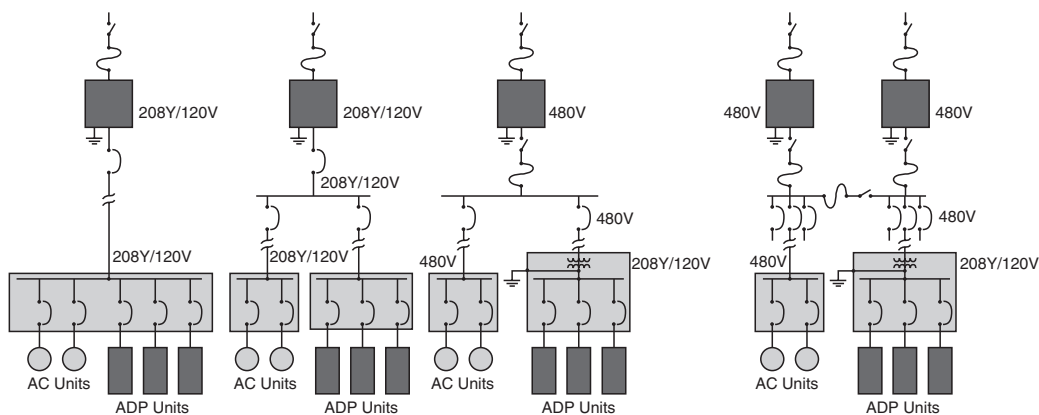


FIGURE 29.3 Separation of loads for noise control.

square miles. Each building has its own grounding system. If these grounding systems are not tied together, a potential difference on the grounding circuit for the communication cable can occur. The idea behind grounding for noise control is to create an equipotential grounding system, which in turn limits or even eliminates the potential differences between the grounding systems. If there is an equipotential grounding system and currents are injected into the ground system, the potential of the whole grounding system will rise and fall and potential differences will not occur.

Supplemental conductors, ground reference grids, and ground plates can all be used to improve the performance of the system as it relates to power quality. Optically isolated communications can also improve the performance of the system. By using the opto-isolators, connecting the communications to different ground planes is avoided. All improvements to the grounding system must be done in addition to the requirements for safety.

Separation of loads is another method used to control noise. Figure 29.3 illustrates this point. Figure 29.3 shows four different connection schemes. Each system from left to right improves noise control.

As seen in Fig. 29.3, the best case would be the complete separation (system on the far right) of the ADP units from the motor loads and other equipment. Conversely, the worst condition is on the left of Fig. 29.3 where the ADP units are served from the same circuit as the motor loads.

29.3 Typical Wiring and Grounding Problems

In this section, typical wiring and grounding problems, as related to power quality, are presented. Possible solutions are given for these problems as well as the possible causes for the problems being observed on the grounding system. (See Table 29.2.)

The following list is just a sample of problems that can occur on the grounding system.

- Isolated grounds
- Ground loops
- Missing safety ground
- Multiple neutral-to-ground bonds
- Additional ground rods
- Insufficient neutral conductors

29.3.1 Insulated Grounds

Insulated grounds in themselves are not a grounding problem. However, improperly used insulated grounds can be a problem. Insulated grounds are used to control noise on the grounding system. This is

TABLE 29.2 Typical Wiring and Grounding Problems and Causes

Wiring Condition or Problem Observed	Possible Cause
Impulse, voltage drop out	Loose connections
Impulse, voltage drop out	Faulty breaker
Ground currents	Extra neutral-to-ground bond
Ground currents	Neutral-to-ground reversal
Extreme voltage fluctuations	High impedance in neutral circuit
Voltage fluctuations	High impedance neutral-to-ground bonds
High neutral to ground voltage	High impedance ground
Burnt smell at the panel, junction box, or load	Faulted conductor, bad connection, arcing, or overloaded wiring
Panel or junction box is warm to the touch	Faulty circuit breaker or bad connection
Buzzing sound	Arcing
Scorched insulation	Overloaded wiring, faulted conductor, or bad connection
Scorched panel or junction box	Bad connection, faulted conductor
No voltage at load equipment	Tripped breaker, bad connection, or faulted conductor
Intermittent voltage at the load equipment	Bad connection or arcing

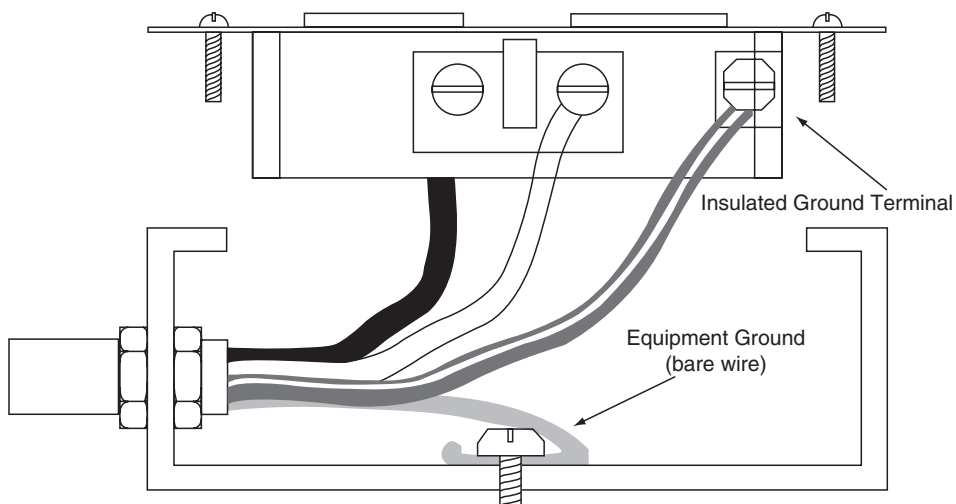
accomplished by using insulated ground receptacles, which are indicated by a “Δ” on the face of the outlet. Insulated ground receptacles are often orange in color. Figure 29.4 illustrates a properly wired insulated ground circuit.

The 1996 NEC has this to say about insulated grounds.

NEC 250-74. Connecting Receptacle Grounding Terminal to Box. An equipment bonding jumper shall be used to connect the grounding terminal of a grounding-type receptacle to a grounded box.

Exception No. 4. Where required for the reduction of electrical noise (electromagnetic interference) on the grounding circuit, a receptacle in which the grounding terminal is purposely insulated from the receptacle mounting means shall be permitted. The receptacle grounding terminal shall be grounded by an insulated equipment grounding conductor run with the circuit conductors. This grounding conductor shall be permitted to pass through one or more panelboards without connection to the panelboard grounding terminal as permitted in Section 384-20, Exception so as to terminate within the same building or structure directly at an equipment grounding conductor terminal of the applicable derived system or source.

(FPN): Use of an isolated equipment grounding conductor does not relieve the requirement for grounding the raceway system and outlet box.

**FIGURE 29.4** Properly wired isolated ground circuit.

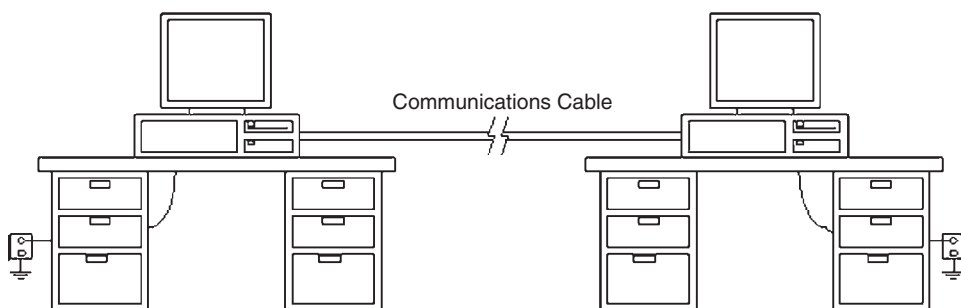


FIGURE 29.5 Circuit with a ground loop.

NEC 517-16. Receptacles with Insulated Grounding Terminals. Receptacles with insulated grounding terminals, as permitted in Section 250-74, Exception No. 4, shall be identified; such identification shall be visible after installation.

(FPN): Caution is important in specifying such a system with receptacles having insulated grounding terminals, since the grounding impedance is controlled only by the grounding conductors and does not benefit functionally from any parallel grounding paths.

The following is a list of pitfalls that should be avoided when installing insulated ground circuits.

- Running an insulated ground circuit to a regular receptacle.
- Sharing the conduit of an insulated ground circuit with another circuit.
- Installing an insulated ground receptacle in a two-gang box with another circuit.
- Not running the insulated ground circuit in a metal cable armor or conduit.
- Do not assume that an insulated ground receptacle has a truly insulated ground.

29.3.2 Ground Loops

Ground loops can occur for several reasons. One is when two or more pieces of equipment share a common circuit like a communication circuit, but have separate grounding systems (Fig. 29.5).

To avoid this problem, only one ground should be used for grounding systems in a building. More than one grounding electrode can be used, but they must be tied together (NEC 250-81, 250-83, and 250-84) as illustrated in Fig. 29.6.

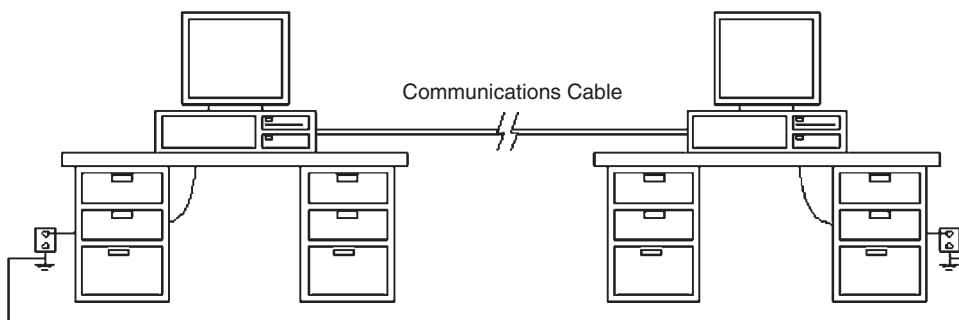


FIGURE 29.6 Grounding electrodes must be bonded together.

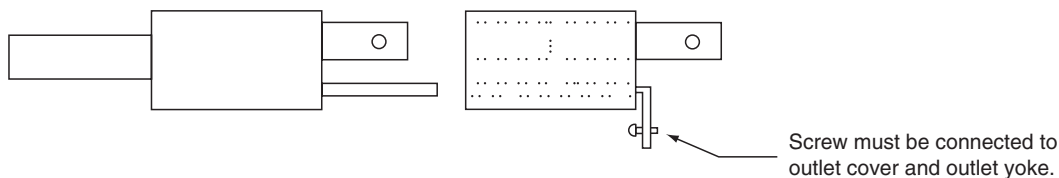


FIGURE 29.7 Proper use of a grounding plug adapter or “cheater plug.”

29.3.3 Missing Safety Ground

As discussed previously, a missing safety ground poses a serious problem. Missing safety grounds usually occur because the safety ground has been bypassed. This is typical in buildings where the 120-volt outlets only have two conductors. Modern equipment is typically equipped with a plug that has three prongs, one of which is a ground prong. When using this equipment on a two-prong outlet, a grounding plug adapter or “cheater plug” can be employed provided there is an equipment ground present in the outlet box. This device allows the use of a three-prong device in a two-prong outlet. When properly connected, the safety ground remains intact. Figure 29.7 illustrates the proper use of the cheater plug.

If an equipment ground is not present in the outlet box, then the grounding plug adapter should not be used. If the equipment grounding conductor is present, the preferred method for solving the missing safety ground problem is to install a new three-prong outlet in the outlet box. This method insures that the grounding conductor will not be bypassed. The NEC discusses equipment grounding conductors in detail in Section 250—Grounding.

29.3.4 Multiple Neutral to Ground Bonds

Another misconception when grounding equipment is that the neutral must be tied to the grounding conductor. Only one neutral-to-ground bond is permitted in a system or sub-system. This typically occurs at the service entrance to a facility unless there is a separately derived system. A separately derived system is defined as a system that receives its power from the windings of a transformer, generator, or some type of converter. Separately derived systems must be grounded in accordance with NEC 250-26.

The neutral should be kept separate from the grounding conductor in all panels and junction boxes that are downline from the service entrance. Extra neutral-to-ground bonds in a power system will cause neutral currents to flow on the ground system. This flow of current on the ground system occurs because of the parallel paths. Figures 29.8 and 29.9 illustrate this effect.

As seen in Fig. 29.9, neutral current can find its way onto the ground system due to the extra neutral-to-ground bond in the secondary panel board. Notice that not only will current flow in the ground wire for the power system, but currents can flow in the shield wire for the communication cable between the two PCs.

If the neutral-to-ground bond needs to be reestablished (high neutral-to-ground voltages), this can be accomplished by creating a separately derived system as defined above. Figure 29.10 illustrates a separately derived system.

29.3.5 Additional Ground Rods

Additional ground rods are another common problem in grounding systems. Ground rods for a facility or building should be part of the grounding system. The ground rod should be connected where all the building grounding electrodes are bonded together. Isolated grounds can be used as described in the NEC’s Isolated Ground section, but should not be confused with isolated ground rods, which are not permitted.

The main problem with additional ground rods is that they create secondary paths for transient currents, such as lightning strikes, to flow. When a facility incorporates the use of one ground rod, any currents caused by lightning will enter the building ground system at one point. The ground potential of

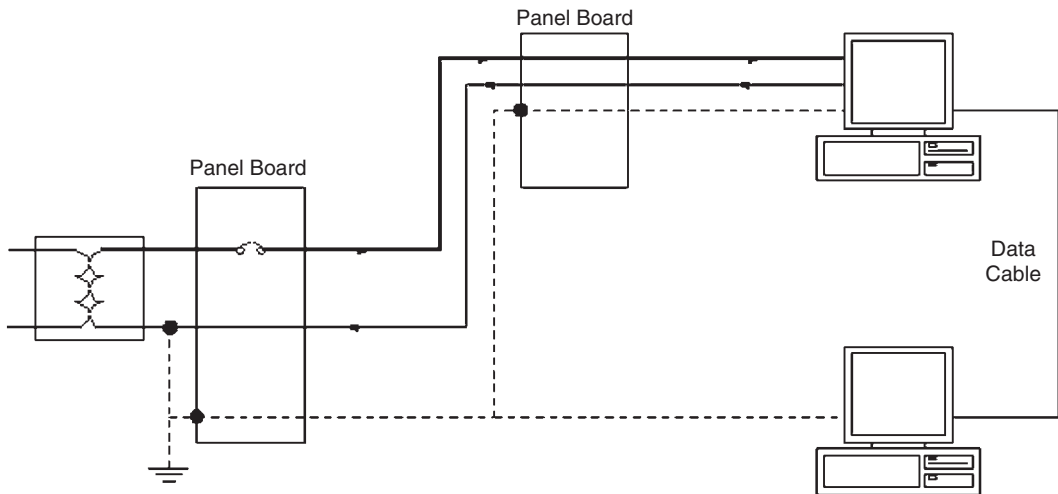


FIGURE 29.8 Neutral current flow with one neutral-to-ground bond.

the entire facility will rise and fall together. However, if there is more than one ground rod for the facility, the transient current enters the facility's grounding system at more than one location and a portion of the transient current will flow on the grounding system causing the ground potential of equipment to rise at different levels. This, in turn, can cause severe transient voltage problems and possible conductor overload conditions.

29.3.6 Insufficient Neutral Conductor

With the increased use of electronic equipment in commercial buildings, there is a growing concern for the increased current imposed on the grounded conductor (neutral conductor). With a typical three-phase load that is balanced, there is theoretically no current flowing in the neutral conductor, as illustrated in [Fig 29.11](#).

However, PCs, laser printers, and other pieces of electronic office equipment all use the same basic technology for receiving the power that they need to operate. [Figure 29.12](#) illustrates the typical power

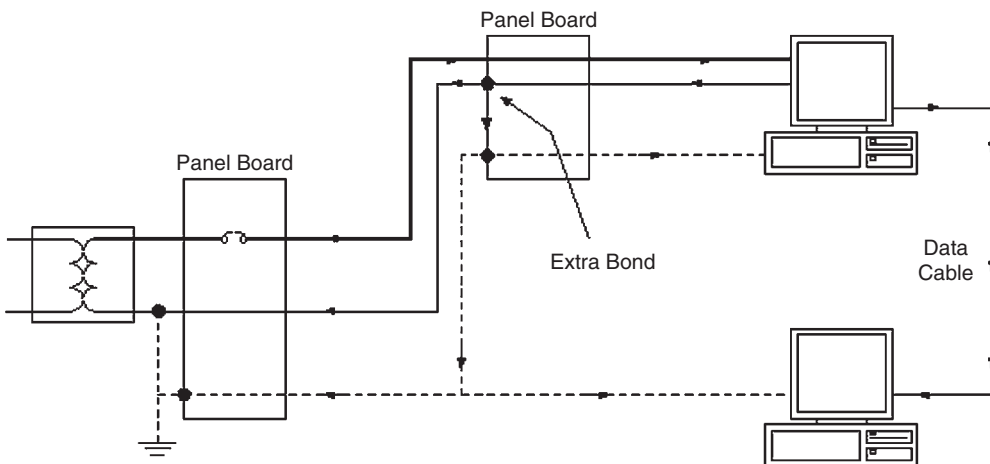


FIGURE 29.9 Neutral current flow with and extra neutral-to-ground bond.

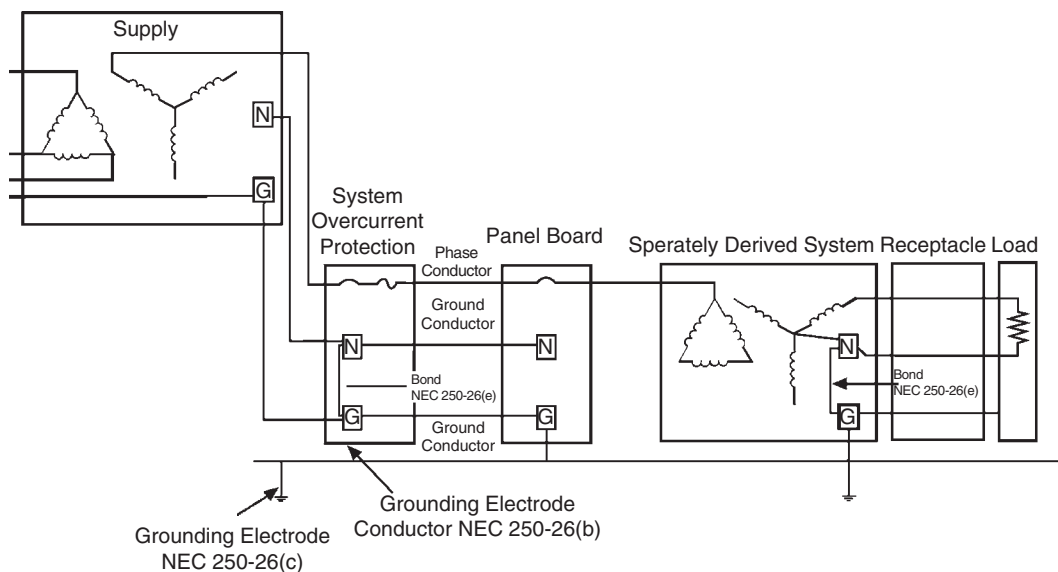


FIGURE 29.10 Example of the use of a separately derived system.

supply of a PC. The input power is generally 120 volts AC, single phase. The internal electronic parts require various levels of DC voltage (e.g., ± 5 , 12 volts DC) to operate. This DC voltage is obtained by converting the AC voltage through some type of rectifier circuit as shown. The capacitor is used for filtering and smoothing the rectified AC signal. These types of power supplies are referred to as switch mode power supplies (SMPS).

The concern with devices that incorporate the use of SMPS is that they introduce triplen harmonics into the power system. Triplen harmonics are those that are odd multiples of the fundamental frequency component ($h = 3, 9, 15, 21, \dots$). For a system that has balanced single-phase loads as illustrated in Fig. 29.13, fundamental and third harmonic components are present. Applying Kirchoff's current law at node N shows that the fundamental current component in the neutral must be zero. But when loads are balanced, the third harmonic components in each phase coincide. Therefore, the magnitude of third harmonic current in the neutral must be three times the third harmonic phase current.

***balanced fundamental currents sum to 0,
but balanced third harmonic currents coincide***

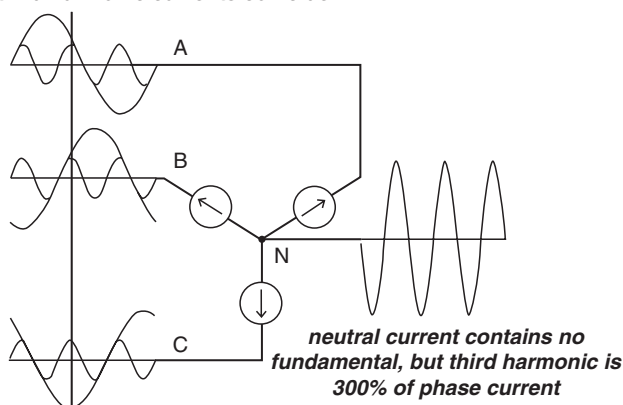


FIGURE 29.11 A balanced three-phase system.

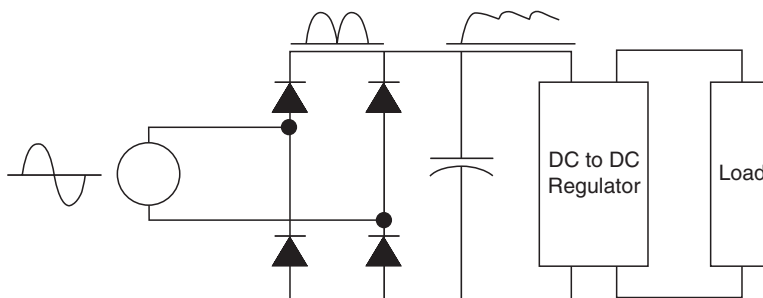


FIGURE 29.12 The basic one-line for a SMPS.

This becomes a problem in office buildings when multiple single-phase loads are supplied from a three-phase system. Separate neutral wires are run with each circuit, therefore the neutral current will be equivalent to the line current. However, when the multiple neutral currents are returned to the panel or transformer serving the loads, the triplen currents will add in the common neutral for the panel and this can cause over heating and eventually even cause failure of the neutral conductor. If office partitions are used, the same, often undersized neutral conductor is run in the partition with three-phase conductors. Each receptacle is fed from a separate phase in order to balance the load current. However, a single neutral is usually shared by all three phases. This can lead to disastrous results if the partition electrical receptacles are used to supply nonlinear loads rich in triplen harmonics.

Under the worst conditions, the neutral current will never exceed 173% of the phase current. Figure 29.13 illustrates a case where a three-phase panel is used to serve multiple single-phase SMPS PCs.

29.3.7 Summary

As discussed previously, the three main reasons for grounding in electrical systems are:

1. Personal safety
2. Proper protective device operation
3. Noise control

***balanced fundamental currents sum to 0,
but balanced third harmonic currents coincide***

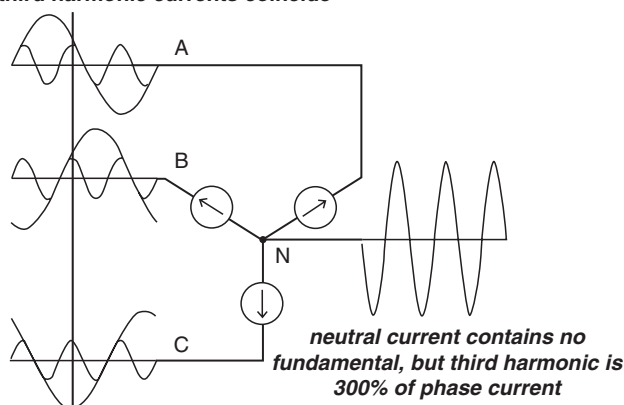


FIGURE 29.13 Balanced single-phase loads.

TABLE 29.3 Summary of Wiring and Grounding Issues

Summary Issues
Good power quality and noise control practices do not conflict with safety requirements. Wiring and grounding problems cause a majority of equipment interference problems. Make an effort to put sensitive equipment on dedicated circuits. The grounded conductor, neutral conductor, should be bonded to the ground at the transformer or main panel, but not at other panel down line except as allowed by separately derived systems.

By following the guidelines found below, the objectives for grounding can be accomplished.

- All equipment should have a safety ground. A safety ground conductor
- Avoid load currents on the grounding system.
- Place all equipment in a system on the same equipotential reference.

Table 29.3 summarizes typical wiring and grounding issues.

29.4 Case Study

This section presents a case study involving wiring and grounding issues. The purpose of this case study is to inform the reader on the procedures used to evaluate wiring and grounding problems and present solutions.

29.4.1 Case Study—Flickering Lights

This case study concerns a residential electrical system. The homeowners were experiencing light flicker when loads were energized and deenergized in their homes.

29.4.1.1 Background

Residential systems are served from single-phase transformers employing a split secondary winding, often referred to as a single-phase three-wire system. This type of transformer is used to deliver both 120-volt and 240-volt single-phase power to the residential loads. The primary of the transformer is often served from a 12 to 15 kV distribution system by the local utility. [Figure 29.14](#) illustrates the concept of a split-phase system.

When this type of service is operating properly, 120 volts can be measured from either leg to the neutral conductor. Due to the polarity of the secondary windings in the transformer, the polarity of each 120-volt leg is opposite the other, thus allowing a total of 240 volts between the legs as illustrated. The proper operation of this type of system is dependent on the physical connection of the neutral conductor or center tap of the secondary winding. If the neutral connection is removed, 240 volts will remain across the two legs, but the line-to-neutral voltage for either phase can be shifted, causing either a low or high voltage from line to neutral.

Most loads in a residential dwelling, i.e., lighting, televisions, microwaves, home electronics, etc., are operated from 120 volts. However, there are a few major loads that incorporate the use of the 240 volts available. These loads include electric water heaters, electric stoves and ovens, heat pumps, etc.

29.4.1.2 The Problem

In this case, there were problems in the residence that caused the homeowner to question the integrity of the power system serving his home. On occasion, the lights would flicker erratically when the washing machine and dryer were operating at the same time. When large single-phase loads were operated, low power incandescent light bulb intensity would flicker.

Measurements were performed at several 120-volt outlets throughout the house. When the microwave was operated, the voltage at several of the 120-volt outlets would increase from 120 volts nominal to

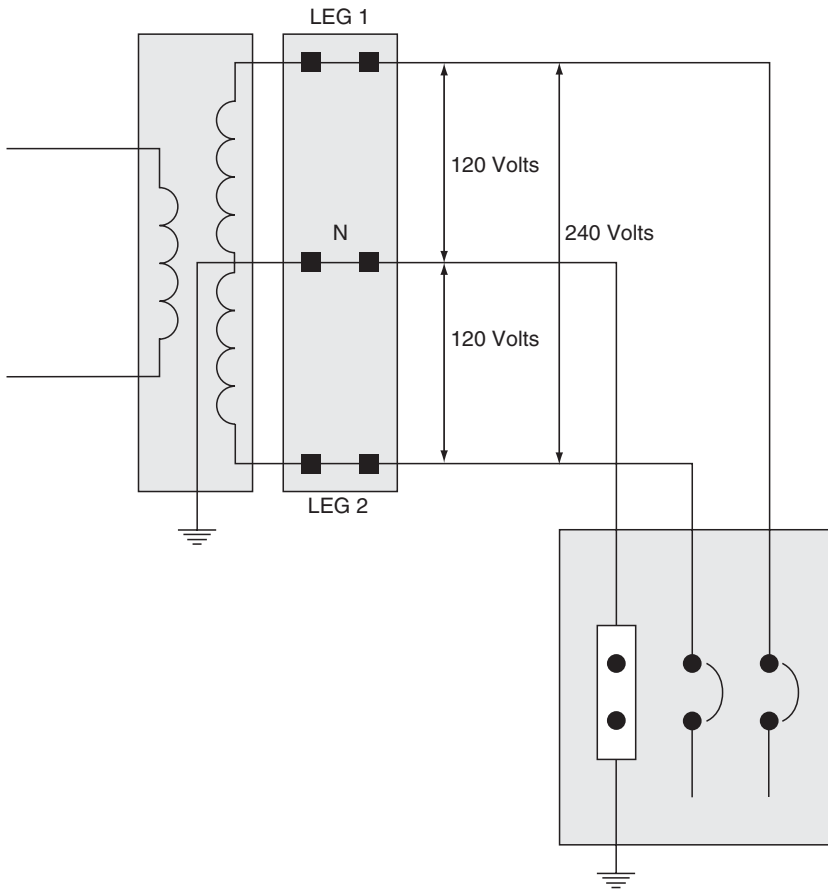


FIGURE 29.14 Split-phase system serving a residential customer.

128 volts. The voltage would return to normal after the microwave was turned off. The voltage would also increase when a 1500-Watt space heater was operated. It was determined that the voltage would decrease to approximately 112 volts on the leg from which the large load was served. After the measurements confirmed suspicions of high and low voltages during heavy load operation, finding the source of the problem was the next task at hand.

The hunt began at the service entrance to the house. A visual inspection was made of the meter base and socket after the meter was removed by the local utility. It was discovered that one of the neutral connectors was loose. While attempting to tighten this connector, the connector fell off of the meter socket into the bottom of the meter base (see Fig. 29.15). Could this loose connector have been the cause of the flickering voltage? Let's examine the effects of the loose neutral connection.

Figures 29.16 and 29.17 will be referred to several times during this discussion. Under normal conditions with a solid neutral connection (Fig. 29.16), load current flows through each leg and is returned to the source through the neutral conductor. There is very little impedance in either the hot or the neutral conductor; therefore, no appreciable voltage drop exists.

When the neutral is loose or missing, a significant voltage can develop across the neutral connection in the meter base, as illustrated in Fig. 29.17. When a large load is connected across Leg 1 to N and the other leg is lightly loaded (i.e., Leg 1 to N is approximately 10 times the load on Leg 2 to N), the current flowing through the neutral will develop a voltage across the loose connection. This voltage is in phase with the voltage from Leg 1 to N' (see Fig. 29.17) and the total voltage from Leg 1 to N will be 120 volts.

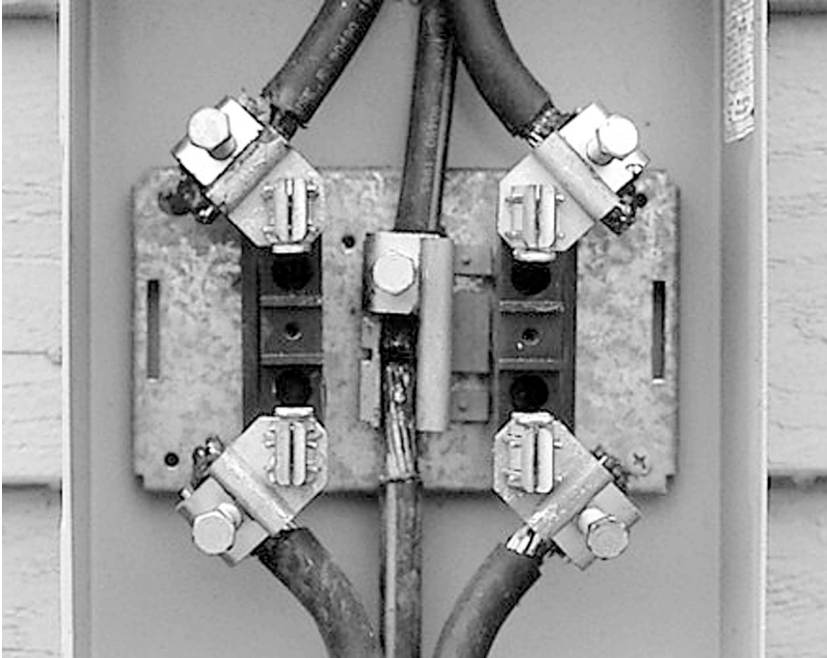


FIGURE 29.15 Actual residential meter base. Notice the missing neutral clamp on load side of meter.

However, the voltage supplied to any loads connected from Leg 2 to N' will rise to 128 volts, as illustrated in Fig. 29.17. The total voltage across the Leg 1 and Leg 2 must remain constant at 240 volts. It should be noted that the voltage from Leg 2 to N will be 120 volts since the voltage across the loose connection is 180° out of phase with the Leg 2 to N' voltage.

Therefore, with the missing neutral connection, the voltage from Leg 2 to N' would rise, causing the light flicker. This explains the rise in voltage when a large load was energized on the system.

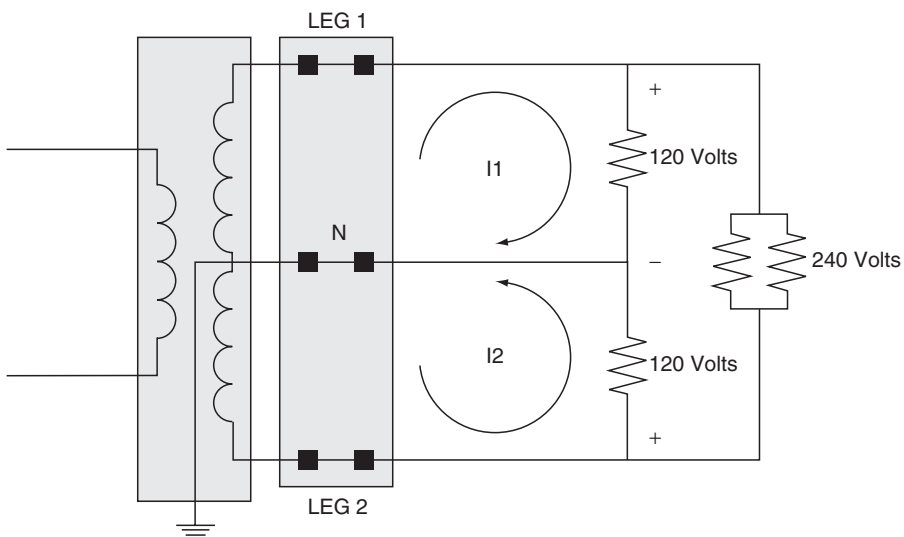


FIGURE 29.16 The effects of a solid neutral connection in the meter base.

